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Ocean Simulation Model for Internal Waves

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Foreword

The effects of the oceanic environment on acoustic propagation, sensor systems, and weaponry have become widely recognized as important in prosecuting modern naval warfare. Cost and time are prohibitive for conducting field experiments to measure these effects under all the conditions that should be expected. Simulation models of the oceanic environment can produce realistic data approximations that can be used in designing and testing systems and tactics. This report describes the first ocean simulation model developed at the Naval Oceanographic and Atmospheric Research Laboratory and provides potential users with the details necessary to implement and operate the model.

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Executive Summary

Oceanographic simulation models are valuable tools for imitating temperature, salinity, density, sound velocity, and other environmental areas of naval interest. The Naval Oceanographic and Atmospheric Research Laboratory was tasked to implement and operate ocean simulation models. This manual presents the theoretical foundations for the first version of the model, the details of the primary model's structure, and the computer programs and instructions for implementing and using the model.

The first version of the model was based on the premise that the most important features of interest to the Navy are produced by internal waves. Subsequent versions of the model will incorporate variability produced by shear, fronts, mixed-layer processes and turbulent mixing. A full three-dimensional, time-varying model is expected in about 3 years.

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I. Introduction

A. Background

Over the past two decades, acousticians have realized that acoustic propagation is greatly affected by the variability in the internal wave field and by the variability of currents and sound velocity on the larger scales of fronts and eddies, (Flatté and Tappert, 1975; Dyson et al., 1976; Desaubies, 1976a, 1976b, 1978; Ewart, 1980, 1989; Macaskill and Ewart, 1984). This significant discovery led to the need to obtain simulations of oceanic density, current, and sound velocity fields. One method for studying the acoustic fluctuations relies on a direct simulation of the ocean environment. A statistical model of the environment can also be directly incorporated into an acoustic model.

Simulations are used to model the performance of proposed instruments, often before these instruments are designed or constructed. This type of modeling is particularly useful when the instrument senses or processes the signal nonlinearly. Use of such simulations can save time and money in the design and construction of sensor systems.

Oceanographic simulations also have great potential utility in designing sampling strategies for hydrographic surveys. A field of simulated data can be easily constructed and one sampling method tested against another. Proper application of this type of testing, if conducted prior to a cruise, could save several days of ship time per cruise.

An ocean simulation model can be defined as a method (an algorithm implemented on a computer) that will provide a representation of a set of fields of oceanic variables over a given space-time domain at a specified resolution. The algorithm can simply be a method for searching a data base, or it can employ sophisticated methods for generating stochastic fields with specified statistics.

B. Project Objectives

The Naval Oceanographic and Atmospheric Research Laboratory (NOARL) was tasked to develop and test a sequence of simulation models for the ocean simulation project. The end product will be the capability to simulate temperature, salinity, density, sound velocity, and current fields in any ocean region over any reasonable time and space domain and resolution. The simulations are intended for use by the acoustics and oceanographic community to provide a well-defined testbed for evaluating environmental effects on acoustic systems, and by the weapons design, nonacoustic ASW and oceanographic communities for similar purposes.

The first version of the simulation model is based on the premise that the features important to the Navy are produced by internal waves. These waves typically have periods between 15 minutes and 24 hours and horizontal wavelengths on the order of tens of meters to tens of kilometers. The waves vertically advect constant density surfaces to produce time- and space-varying fields of temperature, salinity, and sound speed.

Subsequent versions of the simulation model will incorporate variability produced by shear, fronts, mixed layer processes, and turbulent mixing. A full three-dimensional, time-varying model is expected in about 3 years.

C. Purpose of this Manual

This manual provides the simulation model user with information that will assist in understanding the theoretical and numerical bases for the simulation, the details of program structure needed for implementation and maintenance, and provides instructions for using the program suite to generate simulations. This manual describes the algorithms used in the simulation and discusses some of the less obvious numerical methods. The details of the program structure are presented and a guide to program operation follows. The program codes are listed in NOARL Technical Note No. 059. ASCII source code can be obtained from NOARL's Physical Oceanography Branch on 5¼-inch diskette or ½-inch magnetic tape. For copies, please write to: Commanding Officer,

Attn: Code 331, Naval Oceanographic and Atmospheric Research Laboratory, Stennis Space Center, MS 39529-5004.

II. Background and Derivation of Algorithms

A. Stochastic Representation of Internal Wave Field

Internal Waves. The internal wave field is composed of motions in the frequency band between the inertial frequency, f, and the Brunt-Väisälä frequency N. (Strictly speaking, this is the band in which freely propagating internal waves are permitted—forced or evanescent internal waves can exist outside this frequency band.) The sobriquet, internal waves, also implies the existence of a dispersion relation, relating wave frequency to wavenumber.

The best known (and most widely used) model of the internal wave field was first formulated by Garrett and Munk (1972). This model is based on an exponential approximation to the Brunt-Väisälä frequency profile and an approximate fit to observed spectra and cross spectra of density and velocity fields.

Tides. After internal waves, the tides are the second most important sources of rapid fluctuations in the ocean. They can be decomposed into a barotropic and baroclinic component. These have widely separated length scales. The barotropic tide has an extremely large length scale when compared to the internal (baroclinic) tide.

Barotropic Tide. The barotropic tide has such long horizontal length scales, that for most of our modeling effort, it may be taken as constant or slowly varying horizontally and uniform vertically. The tidal current vectors trace out an ellipse in the horizontal plane over a tidal cycle. The primary problem in modeling the barotropic tide is to choose the amplitude of the motion. For the open ocean, the amplitude is taken to be about 1 m, and currents of about 10 cm/sec are assumed.

The barotropic tide is also important, as it interacts with the bottom to generate an internal tide (of the same frequency as the barotropic tide) and higher frequency internal waves, such as lee waves observed at Stellwagen Bank in Massachusetts Bay and propagating solitons in the Western Mediterranean Sea.

Internal Tide. The internal tide is thought to be generated by the coupling of the internal wave field with the barotropic tide in regions where the bottom has a very sharp discontinuity, such as the continental shelf break. The internal tides formed in these regions are radiated into the deep ocean as beams of internal wave energy at tidal frequencies. They often proceed shoreward as internal solitons under favorable density stratification. The generation regions are sometimes found at midocean banks or seamounts.

The largest amplitudes of the internal tide occur on the continental shelves, with the amplitudes in the open ocean being much smaller. DeWitt et al. (1986) have studied the internal M_2 tide in the Rockall Channel area, west of the British Isles. They found that internal tides are consistent with the model of Prinsenberg and Rattray (1975), with most of the energy being in the first vertical mode. The Prinsenberg and Rattray model indicates that the amplitude of the nth mode should be distributed as $(1/n) \cdot \sin(n \pi H_1/H)$, where H_1 is the depth of the shallow region and H is the deep-ocean depth. Local information is not available at present, so the amplitudes of the internal tidal modes are assumed to be proportional to the inverse mode number.

Outline of Basic Garrett-Munk Model. In this simulation effort, the latest version of the "Garrett-Munk spectrum" is used. There are a number of different versions (Garrett and Munk, 1972, 1975, Cairns and Williams, 1975; Desaubies, 1976b, Munk, 1978). The Munk (1978) formulation is used because it incorporates more observational data than the others, and it is defined in a frequency-mode formulation, which is more appropriate to the eigenmode expansion approach. A table of terms and definitions is provided for convenience (Table 1).

The following assumptions are either made explicitly or implicitly in the derivation of the Garrett-Munk (GM) model.

- The Brunt-Väisälä frequency profile is given by $N_0 \exp(-z/b)$, where N_0 is the Brunt-Väisälä frequency at the surface, z is the depth, and b is a scale depth. For the usual GM formulation, $N_0 = 3$ cph and $b = 1300$ m.
- The fields of interest are given by a sum of weighted wave eigenfunctions based on a separated, linear, internal wave equation without shear.
- Local WKBJ-like[1] scaling is valid for all modes.
- The spectra are consistent with observed internal wave spectra.
- The spectrum is separable by mode and frequency.
- The energy associated with each mode can be "smeared" in the ω, κ plane.

The spectral representations used in the most recent formulations (Munk, 1978) for the spectra of vertical

[1] See Nayfeh (1973) for a discussion of the WKBJ approximation method.

Table 1. Terms and definitions.

b	Scale depth in the GM model. Usually 1.3 km.	r	horizontal range.
$B(\omega)$	GM frequency weighting function.	S_u	Spectrum of horizontal velocity.
BV	Brunt-Väisälä.	S_w	Spectrum of vertical velocity.
E	Nondimensional GM energy level, 6.3×10^{-5}.	S_ζ	Spectrum of vertical displacement.
f	Inertial frequency = 2 ≡ sin (latitude).	$T(z)$	Weighting function used in the Numerov method.
$f(x)$	Function of x.	u	Horizontal, eastward velocity component.
F_u	GM form of the horizontal kinetic energy spectrum.	U_j	Horizontal u-velocity, jth mode.
F_w	GM form of the vertical kinetic energy spectrum.	v	Horizontal, northward velocity component.
GM	Garrett-Munk.	V_j	Horizontal, v-velocity, jth mode.
H	Bottom depth.	w	Vertical velocity component.
$H(j)$	GM mode weighting function.	W_j	Vertical velocity, jth mode.
HKE	Horizontal kinetic energy	x	Horizontal, eastward coordinate.
j	Mode number.	y	Horizontal, northward coordinate.
j^*	Mode scale, usually 3.	z	Vertical coordinate.
k	magnitude of horizontal wavenumber.	α	Direction of a section.
m	Vertical wavenumber.	$\beta_j(\omega)$	Weight of jth mode at frequency ω.
n	Direction index.	ζ	Vertical displacement.
$N(z)$	Brunt-Väisälä frequency at depth z.	κ	horizontal wavenumber vector.
N_0	GM base Brunt-Väisälä frequency, usually 3 cph.	$\theta_{nj}(\omega)$	Random direction of nth wave, jth mode, frequency ω.
$\overline{NH}$	Vertically integrated Brunt-Väisälä frequency.	ω	Frequency.
		$\phi_{nj}(\omega)$	Random phase function.

velocity, F_w, and horizontal velocity, F_u, as functions of frequency, ω, mode, j, and local Brunt-Väisälä frequency, are

$$F_w(\omega, j) = b^2 N_0 N^{-1}(z)\,(\omega^2 - f^2)\,E(\omega, j) \quad , (1)$$

$$F_u(\omega, j) = b^2 N_0 N(z)\,(\omega^2 + f^2)\,\omega^{-2} E(\omega, j) \quad , (2)$$

where

$$E(\omega, j) = E\,B(\omega) H(j)\,, \quad (3)$$

$$B(\omega) = 2\pi^{-1} f\,\omega^{-1}\,(\omega^2 - f^2)^{-1/2}\,, \quad (4)$$

$$H(j) = (j^2 + j_*^2)^{-1} / \Sigma (j^2 + j_*^2)^{-1}\,, \quad (5)$$

$$b = 1300 \text{ m}\,, \quad (6)$$

$$N_0 = 3 \text{ cph}\,, \quad (7)$$

$$E = 6.3 \times 10^{-5}\,. \quad (8)$$

The mode scale j_* is assumed equal to 3.

Extension to Realistic Brunt-Väisälä Profiles. To extend the GM model to general profiles of Brunt-Väisälä frequency, a number of further assumptions have been made.

- The displacement and velocity fields can be expressed as a sum of weighted wavefunctions, integrated over the following frequencies: from f to $\min_{\text{range}} \{\max_z [N(z)]\}$.
- The wavefunctions are determined by the separated z-dependent, linear, internal wave equation and local Brunt-Väisälä frequency profile, $N(z)$.
- The vertically integrated energy in each mode has the GM form in frequency and mode.
- In the first-level model, there are no shear effects.

These assumptions result in an energy scaling somewhat different from the GM model. This scaling is discussed in the following section.

Energy Scaling. The general form of the eigenfunction expansion in terms of the wave functions may be summarized as:

$$w(z, r, \alpha, t) = \sum_j \sum_n \int_f^N \beta_j(\omega)\, W_j(\omega; z) \cdot$$

$$\exp\{i\,[x k_j \cos\theta_{nj}(\omega) + y k_j \sin\theta_{nj}(\omega)$$

$$+ \omega t + \phi_{nj}(\omega)]\}\sqrt{d\omega}\,, \quad (9)$$

where $x = r \cdot \cos(\alpha)$, $y = r \cdot \sin(\alpha)$, $W_i(\omega; z)$ = vertical mode of order j at frequency ω, and is the solution to the ordinary differential equation,

$$W_j'' + k_j^2 B\,[N(z), \omega, f\,]\, W_j = 0,$$
$$W_j = 0 \text{ at } z = 0, H. \tag{10}$$

The primes in equation 10 denote differentiation with respect to z and

$$B\,[N(z), \omega, f\,] = \left[\frac{N^2(z) - \omega^2}{\omega^2 - f^2}\right], \tag{11}$$

where

$\beta_j(\omega)$ is contribution from mth mode at frequency ω;

r is range;

α is direction of section;

$\theta_{nj}(\omega)$ and $\phi_{nj}(\omega)$ are independent random variables, uniformly distributed over $[0,2\pi)$;

$\theta_{nj}(\omega)$ is the direction in which the nth wave of mode j is propagating;

$\phi_{nj}(\omega)$ are random phases associated with specific modes, directions and frequencies.

Here, we employ the formalism of Pierson (1955) to represent the ensemble of realizations of a random, stationary, Gaussian process. (See Pierson, 1955, or Kinsman, 1965, for a detailed explanation of the $\sqrt{d\omega}$ formalism.)

The primary problem in reconciling the GM spectral model of the internal wave field arises from the departure of real ocean density profiles from the exponential profile assumed by Garrett and Munk. Because real density profiles have scales of variation much smaller than the (approximate) vertical wavelength of a particular mode, the WKBJ-like approximations used in the GM (Garrett and Munk, 1972) model cannot be fully justified. Much of the formalism of the GM model may be kept, however, by appropriate scaling of the wave functions in a manner consistent with the vertically integrated GM spectra. The derivation of this scaling follows.

Define the orthonormal modes of the vertical velocity as W_i and subject to the relation:

$$\int_0^H W_i W_j\,[(N^2(z) - \omega^2)/(\omega^2 - f^2)]\,dz = \delta_{ij}\,, \tag{12}$$

where W_i and W_j are solutions to the internal wave equation 10 for different modes.

Then define the scaled (U_j, V_j, W_j) as $(U_j, V_j, W_j) = \beta_j(U_j, V_j, W_j)$. The specific horizontal kinetic energy (HKE) of the jth mode at frequency ω, integrated over the entire water column, can be written in terms of the scaled horizontal velocities U and V:

$$\text{HKE} = 1/2 \int_0^H U_j^2 + V_j^2\,dz \tag{13}$$

$$\text{HKE} = 1/2 \int_0^H 1 + \frac{f^2}{\omega^2}\;\frac{1}{k^2}\;\frac{d}{dz}\,W_j{}^2 dz \tag{14}$$

$$\text{HKE} = 1/2 \int_0^H 1 + \frac{f^2}{\omega^2}\;\frac{N^2 - \omega^2}{\omega^2 - f^2}\;W_j^2\,dz \tag{15}$$

$$\text{HKE} = 1/2\,\beta_j^2\;1 + \frac{f^2}{\omega^2}\;. \tag{16}$$

From the GM formulation, equation 2 (Munk, 1978),

$$\text{HKE} = b^2 N_0\;1 + \frac{f^2}{\omega^2}\;E(\omega, j)\int_0^H N(z)\,dz\,. \tag{17}$$

However, if

$$\bar{N} H = \int_0^H N(z)\,dz\,, \tag{18}$$

then

$$\beta_j^2(\omega) = 2b^2 N_0 \bar{N} H\,E(\omega, j) \tag{19}$$

is obtained as the proper scaling for the vertical eigenfunctions of vertical velocity.

Here $b = 1300$ m, $N_0 = 3$ cph $= 0.005236$ rad/sec, $H = 3000$ m (for the test case presented in the section on usage) and $E(\omega,j) = B(\omega)\;H(j)$ as defined in equations 3-5.

If all the random phase terms are combined into $\psi_m(\omega)$, then the expression for w is

$$\begin{aligned} w(z,t) &= \sum_j w_j(z,t) \\ &= \sum_j \int \beta_j(\omega)\,W_j(z;\omega) \\ &\quad \exp\{i\,[\omega t + \psi_j(\omega)]\}\sqrt{d\omega}\,. \end{aligned} \tag{20}$$

The autocorrelation function (Kinsman, 1965) can be constructed as

$$<w_j(t, z)\ w_j(t', z)>$$

$$= \tfrac{1}{2} \int_0^{\infty} \beta_j^2(\omega)\, W_j^2(z;\omega)\, \cos[\omega(t-t')]\, d\omega\ , \quad (21)$$

where $\beta_j(\omega)$ is set to zero, where $\omega < f$ and $\omega > N$. The spectrum of the vertical velocity fluctuations of the jth mode at a given level, z, are thus given by

$$S_w(\omega, z, j) = \beta_j^2(\omega)\, W_j^2(\omega, z)\ , \quad (22)$$

and the total vertical velocity spectrum by the sum over all modes is

$$S_w(\omega, z) = \sum_j \beta_j^2\, W_j^2(\omega, z)\ . \quad (23)$$

The GM relations to the spectra of displacement and horizontal velocity are

$$S_u(\omega, z) = \frac{\omega^2 + f^2}{\omega^2 - f^2}\, \frac{N^2(z)}{\omega^2}\, S_w(\omega, z) \quad (24)$$

and

$$S_\zeta(\omega, z) = \omega^{-2}\, S_w(\omega, z)\ . \quad (25)$$

If $S_w(\omega,z)$ is known, then integrating it in the vertical with the inner product weighting function gives

$$\int_0^H \frac{N^2 - \omega^2}{\omega^2 - f^2}\, S_w(\omega, z)\, dz$$

$$= \sum_j \beta_j^2(\omega) \int_0^H \frac{N^2 - \omega^2}{\omega^2 - f^2}\, W_j^2\, dz$$

$$= \sum_j \beta_j^2(\omega) = 2\, b^2 N_0 \overline{N} H \sum_j E(\omega, j)$$

$$= 2\, b^2 N_0 \overline{N} H\, B(\omega) \sum_j H_j$$

$$= 2\, b^2 N_0 \overline{N} H\, B(\omega)\ . \quad (26)$$

There is a logical inconsistency here, however. Suppose the vertical kinetic energy from the GM spectrum is computed for the jth mode. From integrating Equation 1,

$$\mathrm{VKE} = 2\, b^2 N_0\, (\omega^2 - f^2)\, E(\omega, j) \int_0^H N^{-1}(z)\, dz \quad (27)$$

is obtained. But, by integrating the squared vertical mode velocities, we obtain

$$\mathrm{VKE} = \tfrac{1}{2} \beta_j^2(\omega) \int_0^H W_j^2\, dz$$

$$= b^2 N_0 \overline{N} H\, E(\omega, j) \int_0^H W_j^2\, dz\ . \quad (28)$$

These can be consistent only if

$$(\omega^2 - f^2) \int_0^H N^{-1}(z)\, dz = \overline{N} H \int_0^H W_j^2(z, \omega)\, dz\ . \quad (29)$$

From the orthogonality condition,

$$(\omega^2 - f^2) = \int_0^H (N^2 - \omega^2)\, W_j^2(z, \omega)\, dz\ , \quad (30)$$

we have

$$\int_0^H (N^2 - \omega^2)\, W_j^2(z, \omega)\, dz \int_0^H N^{-1}(z)\, dz$$

$$= \overline{N} H \int_0^H W_j^2(z, \omega)\, dz\ . \quad (31)$$

However, if $N(z)$ is set to equal a constant, then the equality does not hold, so the scaling (26) is not consistent with the GM spectrum for the vertical velocity.

The source of this disagreement can be traced to the WKBJ-like approximation for the vertical wavenumber, $m = kN(\omega^2 - f^2)^{-1/2}$ and the relation that

$$S_u = \frac{m^2}{k^2}\, \frac{\omega^2 - f^2}{\omega^2}\, S_w\ , \quad (32)$$

which arises from the relation between the derivatives of w and the horizontal components of velocity.

Thus, if the GM form for the vertically integrated spectrum of the HKE is taken as our basis for scaling the vertical eigenfunctions, then a spectrum of vertical kinetic energy inconsistent with the GM form is obtained. The consistent form for the spectrum of the vertical kinetic energy is given by equation 23, and the spectrum for the vertical displacements is still related to S_w by equation 25. The spectrum for the HKE can be obtained from

$$S_u(\omega, z, j) = (\beta_j^2/k_j^2)\,(1 + f^2/\omega^2)\,W_j'^{\,2} \tag{33}$$

and

$$S_u(\omega, z,) = \sum_j S_u(\omega, z, j). \tag{34}$$

B. Plotting/Interpolation Methods

The density of the output data is not sufficiently high to produce smooth plots, so the data must be interpolated onto a finer mesh, consistent with the screen resolution. The interpolation is performed by a bilinear function defined over each rectangle in the original output mesh. This method has one drawback: it does not ensure continuity of first derivatives. This flaw is compensated for by the increased speed and does not significantly affect the visual aspect of the plot if the original resolution is moderately high.

C. Export Algorithm

For plotting the fields on an IBM-compatible personal computer (PC) using a 16-color video graphics adapter, the data have been encoded as two-character numerical ASCII groups, varying from 00 to 99. These groups are transmitted over the local area network via Kermit or other convenient file transfer protocol in blocks of 39 pairs and plotted on a PC. A header in the file allows for reading-in scaling and plot generation information. A typical plotting program for a PC is listed in NOARL Technical Note 59.

A more efficient coding algorithm is possible, as only 16 colors are required. The data could be encoded for color level on the generating computer and transmitted with two color codes per byte, an improvement of a factor of 4 in storage. More efficient packing methods are possible and may be used in the future, but most of these methods require much more computational time at both the source and receiver and are prone to transmission errors.

III. Numerical Methods

A. Eigenfunction Calculations

The eigenvalues and eigenfunctions for the internal wave differential equation are computed using the Numerov method. This recursive finite-difference method has the advantage of being very fast and is fifth-order accurate. (The routine was originally written by Dozier (undated manuscript) of Scientific Applications International Corporation (SAIC) and is a part of the original code supplied by Rubenstein, also of SAIC.)

The Numerov method for the differential equation $y'' + f(z)y = 0$ is given by the relation

$$\begin{aligned}[1 + T(z+\Delta z)]y(z+\Delta z) + [1 + T(z-\Delta z)]y(z-\Delta z)\\ = [2 + 10\ T(z)]\ y(z) - \Delta z^6 y^{(6)}/240 + \ldots,\end{aligned} \tag{35}$$

where $T(z) = \Delta z^2\ f(z)/12$.

The integration proceeds from the top and the bottom toward a point z_0 in the oscillatory region of the solution (i.e., where $f(z) > 0$). The eigenvalue is updated until a matched solution is found that satisfies continuity of the function and its first derivative at the matching point to the desired degree of accuracy. The mode is checked by ensuring that the number of zero crossings of the solution matches the mode number. This method occasionally fails when the eigenvalues are extremely close together, but this problem does not appear to be serious in most circumstances.

B. Integration Method

Several methods are available to estimate integrals using numerical techniques. The question arose as to which would provide a better estimat of the simulated fields. The result of a number of tests was, that due to the random phase function, no convergence exists other than a convergence to the Gaussian probability distribution function over an ensemble of realizations of the integral. We found that the simplest form of numerical integration, rectangular approximation, gave results as good as any other method and was more efficient.

C. Choice of Integration Subintervals

If a uniform grid is chosen over which to perform the numerical integration, then the grid must be made very fine to adequately resolve the structure of the GM spectrum near the inertial frequency. To use a coarser mesh while still resolving the spectrum, a logarithmic transformation is performed on the ω axis. This operation requires that the functional form

computed over the sum be modified and consideration taken in the choice of the differential weights.

The transformation is given by

$$\int_a^b f(x)\,dx = \int_a^b x\,(f)\,d(\ln x) = \int_{\ln a}^{\ln b} e^y f(e^y)\,dy\,. \tag{36}$$

The form on the left is exactly equal to that on the right, but if there is a singularity in $f(x)$ at $x = 0$, and a is near 0, then the form on the left provides a greater accuracy for the same number of terms in the sum or, conversely, less terms for the same accuracy. As an example for $f(x) = x^{-v}$, $a = 0.001$, $b = 5.0$, Gaussian quadrature did not reproduce the answer to better than 30%, while the form on the right agreed with the true answer to within the roundoff error of the computer. This transformation is easily modified for singularities in $f(x)$ at points different from $x = 0$. For the estimation of the internal wave field, the logarithmic form has been chosen, because the singularities in the GM spectra are located at $\omega = f << N$.

When computing the integral, it was necessary to compute the locations of the ends of each subinterval in the transformed space to properly resolve the square root of the differentials.

D. Problem of Probability Distribution Due to Finite Summation

The problem encountered here arises from the necessity of approximating the integral (9) as a finite sum over a set of intervals on the ω axis. The probability distributions of each component of the sum are Cauchy distributions; thus, the sum will be a sum of Cauchy distributions. As the sum approaches the limit of the integral, the probability distribution of the sum along the time axis or across the ensemble at given times will approach a Gaussian distribution almost surely (i.e., as the limit in the mean).

The computation has been modified somewhat to produce a rapid approach to a Gaussian distribution with few terms in the sum. The method is to add a small random phase that varies linearly in time to the constant (in time) random phase-that is, to replace $\phi_{nj}(\omega)$ in equation 9 with $\phi_{nj}(\omega) + \varepsilon\, \psi_{nj}(\omega)\, t$, where ε is a small number and $\phi_{nj}(\omega)$ and $\psi_{nj}(\omega)$ are random variables, uniformly distributed over $(0, 2\pi]$.

IV. System and Program Structure

A. System Structure

Simulation Model. The design philosophy for the simulation model is based on simulating processes in the ocean (or, alternatively, regions in ω, κ space) in order of their energetic importance on the time scales of interest, typically scales of hours to days. Because the most energetic part of the oceanic spectrum appears in the internal wave band, modeling the internal wave field has begun, and is followed by internal tides, mesoscale features, fronts and eddies, and large-scale features, in that order. The larger scale features are important to the smaller scales in that they control the dynamics of the internal wave field through the mean density field and mean shear field, but they will be incorporated in future versions of the model.

The first version of the simulation model was designed to provide global geographic coverage of the ocean and seasonal variations. Several databases exist, but the Levitus 5° database (Levitus, 198?) was chosen for the initial modeling based on storage considerations. This database is used to define stratification by providing spatially dependent profiles of temperature and salinity from which the density field is computed. The oceanic variability is produced by advecting the temperature and salinity fields by vertical wave motions at given positions and times, based on a variation of the GM internal wave model.

To make the first-level ocean simulation model generally useful, it was necessary to ensure that the model could be successfully run on a variety of computers and that the output data would be compatible between different machines and operating systems. This requirement has forced restrictions on the source code to ensure portability of the program and compatibility of the data. At present, the model has been run on VAX/VMS and CONVEX/UNIX systems. The restrictions are not onerous, however. They consist primarily of adhering to the Fortran 77 conventions. Some differences still exist between operating systems, that prevent the code from being completely portable (e.g., the CONVEX uses the convention that the record length parameter in opening direct access files is given in bytes, whereas the VAX convention specifies the record length parameter in 4-byte words).

Program MODEL1 is version 1 of the simulation model. Its output is a time series of vertical sections of vertical displacement, temperature, salinity, and three velocity components. A diagnostic file provides timing information on the VAX but not on the CONVEX.

Export Programs. Programs are available for exporting the ocean simulation model output from binary format into ASCII format. While binary formatted files require less storage space, problems might arise when transferring the files to computers

with different hardware architectures. For example, when transferring files from a VAX/VMS system to a CONVEX system, the byte order must be reversed. Binary characters can also be interpreted as control characters. In ASCII format, the data are more easily transferred to other computers due to the non-machine-specific structure of ASCII files.

Program MODEL1_EXPORT computes model field data produced by the ocean simulation model for plotting on PCs. Interactive prompts query for necessary input and the program produces an ASCII file. Plots can then be produced on the PC using the data in the ASCII file.

Program MODEL1_SV_EXPORT uses the ocean simulation model binary output file to produce an ASCII file containing sound velocity data for transfer to other computers.

Program ASCLEV converts the Levitus data file from binary, direct access format into ASCII, sequential format.

Program LEVASC converts the Levitus data file from ASCII, sequential format into binary, direct access format. Binary format is used by the ocean simulation model.

Diagnostic Programs. Several diagnostic programs are available for evaluating model output. This suite of programs provides a variety of functions, which includes generating data listings, creating plots, and examining energy levels.

Program MODEL1_PLOT computes and plots model fields on the DEC GKS Workstation 2000. No files are produced. This program is intended to provide a high-resolution, quick look at the data but suffers from the lack of a hard-copy device on the GKS workstation.

Program MODEL1_CONTOUR computes and plots model fields as contours. A DISSPLA metafile is produced as output. The metafile may be plotted using the DISSPLA postprocessor.

Program MODEL1_ENERGY computes internal wave energies as plot fields. Horizontal and vertical distributions are plotted. DISSPLA metafiles are produced as output. The metafile may be plotted using the DISSPLA postprocessor, DISSPOP.

Program MODEL1_UVW_READ reads the .AUX and .UV output files from the ocean model. The velocity fields U, V, and W are displayed on the user's terminal screen.

Program MODEL1_CTL_LIST lists the control information file MODEL1.CTL. This file contains information relating to program restart and eigenmode/eigenvalue control and use.

Program MODEL1_LOOK lists model displacement fields on the user's terminal screen. This program is primarily intended as a means of determining whether the typical values of the fields are reasonable.

Program MODEL1_EIGLOOK lists and plots eigenmodes and eigenvalues of the internal wavefunctions produced and stored by MODEL1. The plots are produced as a DISSPLA metafile and can be plotted using DISSPOP.

Program MODESUB_TEST computes the internal wave modes for a Brunt-Väisälä frequency profile and plots them. The plots are generated as DISSPLA metafiles that can be plotted using DISSSPOP.

Program DISPERSION produces modal dispersion diagrams for a Brunt-Väisälä frequency profile at a given location and season. Output diagrams are written as DISSPLA metafiles.

PC Plotting. Output from the ocean simulation model consists of binary and ASCII files. To avoid problems associated with transferring files between different hardware architectures, binary files should be converted into ASCII format before being transferred to PCs. However, ASCII-formatted files require more disk storage than binary. If storage constraints prohibit binary-to-ASCII conversion, commercial and public domain software is available (e.g., Kermit) for binary file transfers between different computers. The export programs described earlier facilitate data transfer to PCs.

B. Program Structure

Diagrams that show program structure and provide comprehensive details of the main program and its associated subprograms are presented in the appendix. Also included are program layering diagrams, which provide a summary of the level of external subroutine calls. These diagrams provide the programmer with an outline of the manner in which the subprograms are called, the input and output functions, and the logic flow.

C. Data Structures

Data structures exist as binary, ASCII, and DISSPLA metaplot files. These files are used as program input, are created as program output, and are stored as disk files on the resident computer system. Interactive program prompts acquire necessary information, other than that stored as disk files, for successful program execution.

Input Files. LEVITUS.DAT, a climatological atlas of the world ocean is based on Levitus (1982). The

ocean simulation model requires LEVITUS.DAT as input. LEVITUS.DAT is an unformatted, direct access file requiring 7.29 Mbytes, or 14,580 VMS blocks, of disk storage. The record structure consists of 180 fields of REAL*4 data, including number of temperature observations, mean temperature (in units of degrees centigrade), standard deviation, number of salinity observations, mean salinity (in units of parts per thousand or practical salinity units), and standard deviation.

Output Files. MODEL1.DAT is an unformatted direct access file that contains displacement, modified temperature and salinity, and sound velocity fields. The record structure consists of 4*NZ fields of floating point data where NZ is the number of depths. Table 2 summarizes the output files for this model.

MODEL1.AUX is an unformatted, direct access file that contains defining parameters (labeled) that should be used to augment data in MODEL1.DAT. The record structure consists of 3*NZ fields, where NZ is the number of depths.

MODEL1.UV is an unformatted, direct access file that contains the velocity fields U, V, and W. The record structure contains 3*NZ fields, where NZ is the number of depths.

MODEL1.EIG is an unformatted, direct access file that contains modal eigenvalues and eigenfunctions for W and k. The record structure contains NZ+1 fields, where NZ is the number of depths.

MODEL1.CTL is an unformatted, direct access file that contains control information relating to program restart and eigenmode/eigenvalue control and use. The record structure contains five fields.

DISSPLA META-PLOT FILES contain a non-device-specific file of data from which plots can be generated using a device-specific postprocessor. The software used for terminal and hardcopy graphics is Computer Associates' DISSPLA. The intermediate metaplot files are named POPFIL.DAT.

V. Usage

The ocean simulation model has been executed on DEC VAX/VMS 11/750 and MicroVAX II systems and on the CONVEX UNIX system. Adherence to most Fortran 77 standards has enabled program portability between the VAX and CONVEX systems.

Table 2. Ocean Simulation Model Output files.

FILE NAME	FMT	ACC	RECL	VARIABLES		RECORD STRUCTURE
MODEL1.DAT	U	D	4*NZ	Real	U,V,W, Z	(U(i),V(i),W(i), Z(i), i=1,NZ)
MODEL1.AUX	U	S	3*NZ	Real	NT,NX,NZ,DT, DX,DZ,T0,LAT, LON,AZ	NT,NX,NZ,DT, DX,DZ,T0,LAT, LON,AZ
MODEL1.UV	U	D	3*NZ	Real	U,V,W i=1,NZ)	(U(i),V(i),W(i),
MODEL1.EIG	U	D	NZ+1	Real	k W	k,(W(i),i=1,NZ)
MODEL1.CTL	U	D	5	Rec 1,	Int. NX Real DX,XMAX	NX,DX,XMAX
				Rec 2,	Int. NZ Real DZ,ZMAX	NZ,DZ,ZMAX
				Rec 3,	Int. NT Real DT,TMAX	NT,DT,TMAX
				Rec 4,	Int. LAT,LON LAT1,LON1 Real AZIMUTH	LAT,LON,LAT1,LON1, AZIMUTH
				Rec 5,	Int. IT0,NDIR Real T	T,IT0,NDIR

Notes:

- File format (FMT) is denoted as unformatted, U
- File access (ACC) is denoted as D for direct access, or S for Sequential

A. VMS (DEC-VAX)

The ocean simulation model can be executed either interactively or in batch mode. The Levitus climatological atlas, LEVITUS.DAT, is required as part of program input. Interactive prompts acquire remaining necessary program information.

Execution of the MODEL1 simulation program with the input described in section V.E on the VAX 11/750 required 47.49 minutes of processing time. The 11/750 possessed 7 Mbytes of memory and a floating-point accelerator. The system (SYSGEN) parameter, VIRTUALPAGECOUNT, was set to 21,384. User accounts required modification of the parameter PGFLQUO from 16,000 blocks to 20,000 blocks.

Because the 11/750 was used by other interactive users, executions were performed in batch mode. This method made it possible to avoid resource depletion and slowing down of the system for other interactive users.

On the MicroVAX II, the same program and input required 32.60 minutes. This MicroVAX is a standard system containing 10 Mbytes of memory and a floating-point accelerator. The SYSGEN parameter, VIRTUALPAGECOUNT, was set to 20,000. Users' accounts required setting the parameter PGFLQUO from 16,000 blocks to 20,000 blocks.

B. UNIX

The ocean simulation model has been recompiled and executed on a CONVEX computer system. The source code required minimal revision to reconcile the record length parameters, as discussed. The source code was compiled using the following command line

```
fc -O2 model1.f -o model1.
```

The test program and input ran in 3.38 minutes. To run the model, the associated files had to be deleted before starting the model. For details, see the examples in section V. E.

C. MS-DOS

The ocean simulation model has not been tested on a PC. The degree of software modification is dependent upon the PC Fortran implementation. Model output can be converted to ASCII format and down loaded onto PCs for plotting and listing.

D. Program Input Prompt Descriptions

The ocean simulation model requires user input for execution. If MODEL1 has already been executed, then existing output files are used to avoid time-consuming recalculations. The file MODEL1.EIG contains eigenvalue/eigenfunction data and can be reused. Restart information is saved in MODEL1.CTL. MODEL1 automatically searches for the existence of these files before computation. The following input is required.

Latitude and Longitude Prompts: Floating-point values for latitude, longitude, and direction of section are required. Invalid coordinates are flagged and the prompt is reissued.

Season Prompt: A character string is required. The valid responses are WINTER, SPRING, SUMMER or FALL. Because MODEL1 prompt responses are case sensitive, only upper-case values are valid.

Maximum and Delta Ranges in km Prompt: The range is the horizontal distance (in kilometers) of the section. The maximum range is the total length of the section, and delta range provides the horizontal resolution for the calculation. In the present version of MODEL1, the total number of ranges must be less than or equal to 512.

Maximum and Delta Depths in m Prompt: The maximum and delta depths correspond to ranges but apply to the vertical coordinate. If the depth increment is chosen such that the number of depth intervals would be greater than 512, then the program sets the number of intervals to 512 and rescales the depth increment accordingly.

Maximum and Delta Times in s Prompt: The program allows the time series of the vertical sections to be calculated. The times are specified in seconds. No limits are placed on the ranges of the input times, but if the number of time increments is too large, then the available storage on the computer system can be exceeded.

Number of Directions in Isotropic Case Prompt: For the isotropic case (the only one presently allowed), each mode and frequency can have up to 50 plane waves propagating at different, randomly chosen directions. The number of such waves is a user input. For most purposes, NDIR = 3 seems to produce reasonable results.

Number of Eigenvalues (NEIG), Modes (NMODES), and Frequencies (NF) prompt: Integer values for NEIG, NMODES, and NF are required. Default values will be used if zeroes are entered where NEIG = 1000, NMODES = 5, and NF = 8. If NEIG is not set to 1, MODEL1 will compute as many eigenfunctions per mode and frequency as there are steps in the horizontal. If NEIG = 1, only the first position will be used to determine the Brunt-Väisälä

frequency profile and associated eigenfunctions. If NMODES = 0 and NF = 0, the defaults will be substituted; otherwise, NMODES and NF will equal the user-specified value.

Garrett-Munk Brunt-Väisälä Frequency Profile Prompt: A character string (YES or NO) is required. If YES, a generic Brunt-Väisälä frequency profile is used in place of the real profile.

M2 Internal Tide Prompt: A character string (YES or NO) is required. If YES, a generic internal tide (M2) is included in the model. In this case, a 1-m internal tidal amplitude will be assumed.

At the end of input prompts, MODEL1 displays some of the user-supplied information and computed values.

E. Sample Program Execution

VAX/VMS. A sample program execution with inputs follows where program input is shown in boldface type. Additional run-time information is available in the General Description Section for MODEL1. The program produces some output other than the prompts. This output is intended to guide the user. For example, if the RESTART parameter is false, then it tells the user that the program will be reinitialized. If it is true, then the user has the choice of reinitializing the program or continuing from where it left off. The *EXIST parameter tells the user whether or not the file continues to exist. If only some exist, it is probably be better to delete all the files and reinitialize. After all inputs are satisfied, a summary of the parameters that will be used to generate the model are listed. These parameters are for information only and play no part in the subsequent operation of the model.

$ RUN MODEL1

RESTART = F
AUXEXIST F
DATEXIST F
CTLEXIST F
EIGEXIST F
RESTART = F

*******OCEAN SIMULATION MODEL*******
VERSION 1.0

Enter latitude, longitude and direction of section in decimal degrees.

30,-70,123
Enter season (WINTER, SPRING, SUMMER OR FALL)

SUMMER
Enter maximum and delta ranges in km,
maximum and delta depths in m,
maximum and delta times in s

40,.1
3000,10
100.,500.
ENTER THE NUMBER OF DIRECTIONS TO USE IN ISOTROPIC CASE
3
ENTER NEIG, NMODES, NF
1,0,0
DO YOU WANT GENERIC GARRET-MUNK BVF PROFILE?
NO
DO YOU WANT M2 INTERNAL TIDES?
NO

INPUT DATA
****

Latitude = 30.000
Longitude = -70.000
Azimuth = 123.000

Xmax = 40.000
Zmax = 3000.000
Tmax = 100.
NX,NZ,NT,NDIR = 401 301 1 1

COMPUTED VALUES

LAT = 30.000 LON = -70.000
LAT1 = 25.000 LON1 = -65.000
Reduced Azimuth = 135.000

Output from this simulation can be reviewed with the diagnostic programs. Figure 1 shows a VMS command file that executes the program MODEL1.

CONVEX/UNIX. Example shell files listings to run the model are shown in Figure 2. These files are mutually interdependent. One important note in running the program on the CONVEX/UNIX system is that the LEVITUS.DAT file must be named in upper-case characters and must reside in the same directory (subdirectory) as the MODEL1 program.

F. General Description

MODEL1. The ocean simulation model is an interactive, computation-intensive program. Because of the high number of iterations needed by eigenfunction/eigenvalue computations, MODEL1 is computer bound. To save processing time, MODEL1 can use existing files from previous executions. Significant time can be saved by reusing output files.

```
$! VAX/VMS COMMAND FILE FOR EXECUTING
$! OCEAN SIMULATION MODEL, MODEL1
$!
$! REMOVE ANY PRE-EXISTING OUTPUT FILES
$PURGE
$DEL DEBUG.DAT;*
$DEL DIAGNOSTICS.DAT;*
$DEL MODEL1.DAT;*
$DEL MODEL1.AUX;*
$DEL MODEL1.EIG;*
$DEL MODEL1.CTL;*
$DEL MODEL1.UV;*
$!
$!
$! BEGIN EXECUTION
$RUN MODEL1
30,-70,135
SUMMER
40,.1
3000,10
1,100
3
1,0,0
NO
NO
```

Figure 1. VAX/VMS Command file listing for running the test case for MODEL1.

```
File: modrun
#
clean
model1 < input.dat
time

File: clean
# cd \bigone\briggs
ls
rm MODEL1.CTL
rm MODEL1.DAT
rm MODEL1.AUX
rm MODEL1.EIG
rm MODEL1.UV
rm DEBUG.DAT
rm DIAGNOSTICS.LIS
ls

File: input.dat
30.,-70.,135.
SUMMER
40.,I0
3000.,10.
1.,100.
3
1,0,0
NO
NO
```

Figure 2. CONVEX/UNIX Shell command file listings for running the test case for MODEL1.

Automatic inquiry is made for the presence of MODEL1 output files. If all files are found to exist, then MODEL1 will attempt to use them. An error will occur if these files were produced from an execution with an unsuccessful program termination. When all files do not previously exist, MODEL1 creates a new set.

Section V.E contains a sample program execution. Note that immediately after starting the program, MODEL1 reports whether previous output files exist. An F (FALSE) indicates no existence and T (TRUE) indicates the files exist.

Storage requirements increase as values for the number of modes (NMODES) and the number of frequencies (NF) increase. Array elements are computed with the formula NMODES*NF*NZ*NX, where NZ is the number of depths and NX is the number of points on the horizontal region.

MODEL1_EXPORT. Initial information about time (NT), horizontal region (NX), depth (NZ), and delta values (DT, DX, DZ), are displayed. Prompts are used to acquire desired plot type and iteration number. These inputs are used as indices for reading MODEL1.DAT. Output is written in ASCII format to a file named MODEL1.PC.

MODEL1_SV_EXPORT. Only one prompt, for iteration number, is issued. Data contained in MODEL1.DAT are used to compute sound velocity. Output consisting of horizontal, depth, and sound velocity data is written to an ASCII-formatted file named MODEL1_SV_ASCII.

LEVASC. No interactive input is required. LEVASC reads LEVITUS.DAT (direct access) and writes out the contents in ASCII format to a file named LEVITUS.ASC.

ASCLEV. No interactive input is required. ASCLEV reads LEVITUS.ASC (ASCII format) and writes out the contents in direct access format to a file named LEVITUS.DAT.

MODEL1_PLOT. High-resolution color plots are available on the DEC GKS workstation. MODEL1_PLOT is an interactive program that prompts for desired fields and, using the file MODEL1.DAT, computes plot fields for display on the GKS high-resolution color monitor.

MODEL1_CONTOUR. Prompts are used to acquire the name of the file and fields to be plotted. DISSPLA metafiles that contain contour plots are generated by MODEL1_CONTOUR. Figure 3 contains several examples of program execution. The output metafile must be postprocessed for device specifications. Sample output plots are displayed in Figures 4 through 7.

MODEL1_ENERGY. Only one prompt is issued. MODEL1_ENERGY automatically opens files (MODEL1.AUX, MODEL1.DAT and MODEL1.UV) that contain data used in computations. If a generic Garrett-Munk Brunt-Väisälä profile is used, then a reply of YES should be used. (In all other cases, a reply of NO should be used.) In this case, the computed energy profiles are estimated. Summary information is written to an ASCII file named ENERGY.LIS.

```
$! COMMAND FILE FOR USING MODEL1__CONTOUR TO CREATE PLOT
$! FILES OF OCEAN SIMULATION MODEL1 FIELDS ZD, TD, SD, AND SV
$!
$! NOTES:
$! "STD00001.DAT" IS THE DISSPLA DEVICE SPECIFIC FILE
$! NAME FOR THE DEC LN03 LASER PRINTER.
$!
$! DISSPLA APPENDS PLOTS TO EXISTING DEVICE SPECIFIC FILES.
$! DELETE OR RENAME EXISTING VERSIONS TO AVOID UNINTENTIONAL
$! PLOT APPENDING.
$!
$! "DISS105" IS A COMMAND WHICH INVOKES THE DISSPLA
$! POST-PROCESSOR. THE POST PROCESSOR GENERATES
$! DEVICE SPECIFIC PLOT FILES. HERE, THE LN03 SPECIFIC
$! PLOT FILE IS NAMED STD00001.DAT
$!
$! "LN03" IS A COMMAND THE SENDS A FILE TO THE LN03
$! PRINT QUEUE
$!
$SET VERIFY
$DELETE STD00001.DAT;*                ! AVOID PLOT APPENDING
$PURGE
$!
$RUN MODEL1__CONTOUR                  ! PLOT VERTICAL DISPLACEMENT
MODEL1                                ! INPUT DATA FILE NAME
ZD                                    ! FIELD TO PLOT
$DISS105                              ! CREATE DEVICE SPECIFIC FILE
12                                    ! POST-PROCESSOR DIRECTIVE
DRAW=1-END$                           ! POST-PROCESSOR DIRECTIVE
$LN03 STD00001.DAT                    ! PRINT THE PLOT FILE
$!
$RUN MODEL1__CONTOUR                  ! PLOT TEMPERATURE ANOMALY
MODEL1
TD
$DELETE STD00001.DAT;*
$DISS105
12
DRAW=1-END$$RUN MODEL1__CONTOUR
$LN03 STD00001.DAT
$!
$RUN MODEL1__CONTOUR                  ! PLOT SALINITY ANOMALY
MODEL1
SD
$DELETE STD00001.DAT;*
$DISS105
12
DRAW=1-END$
$LN03 STD00001.DAT
$!
$RUN MODEL1__CONTOUR                  ! PLOT SOUND VELOCITY ANOMALY
MODEL1
SV
$DELETE STD00001.DAT;*
$DISS105
12
DRAW=1-END$
$LN03 STD00001.DAT
$PURGE
```

Figure 3. VAX/VMS Command file for producing contour plots of fields generated by MODEL1.

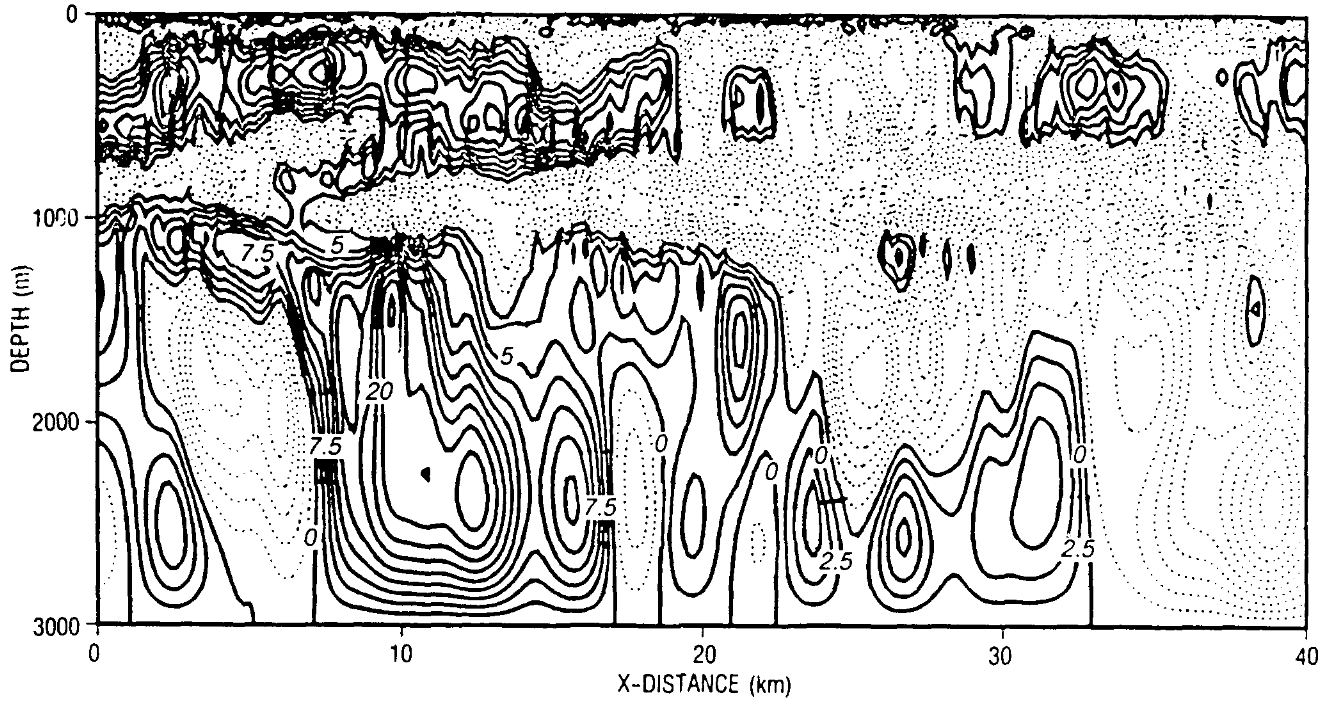

Figure 4. Contour plot of vertical displacement, produced by MODEL1_CONTOUR. Contour interval = 2.500.

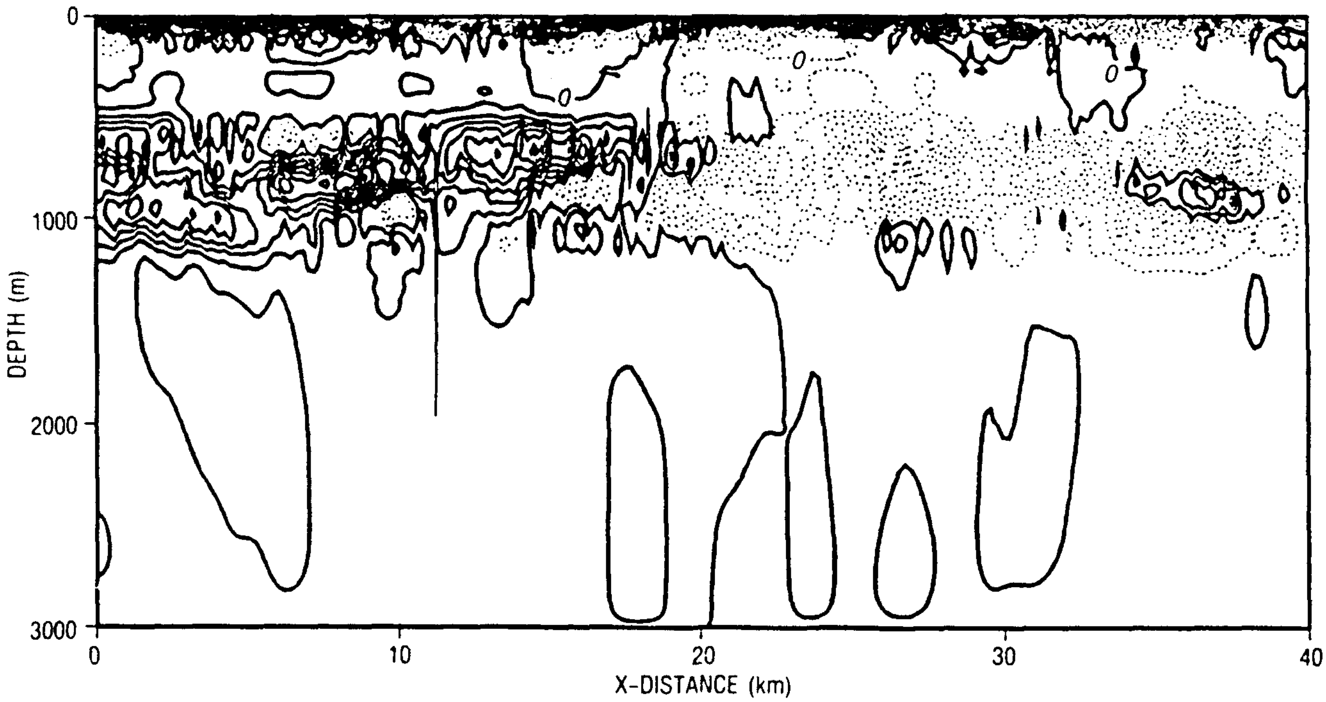

Figure 5. Contour plot of temperature anomaly, produced by MODEL1_CONTOUR. Contour interval = 0.050.

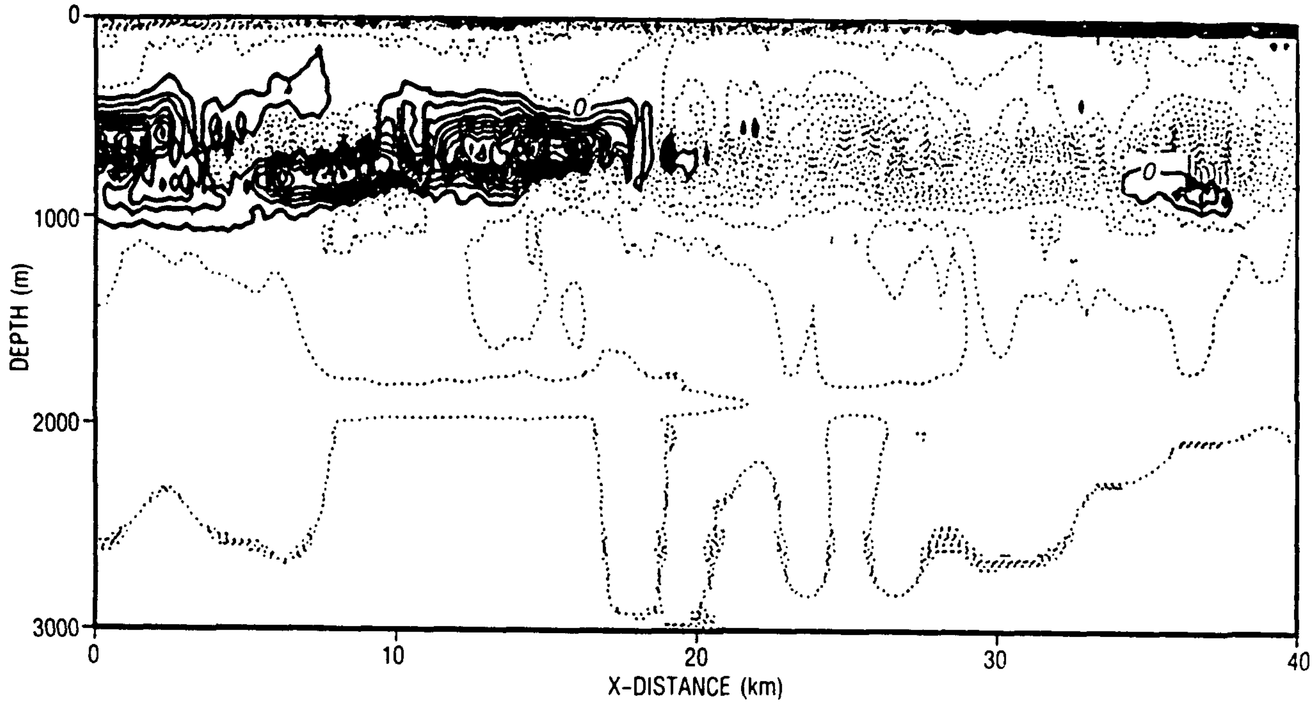

Figure 6. Contour plot of salinity anomaly, produced by MODEL1_CONTOUR. The ragged contour at the bottom of the plot is an artifact produced by a nearly zero anomaly. Contour interval = 0.005.

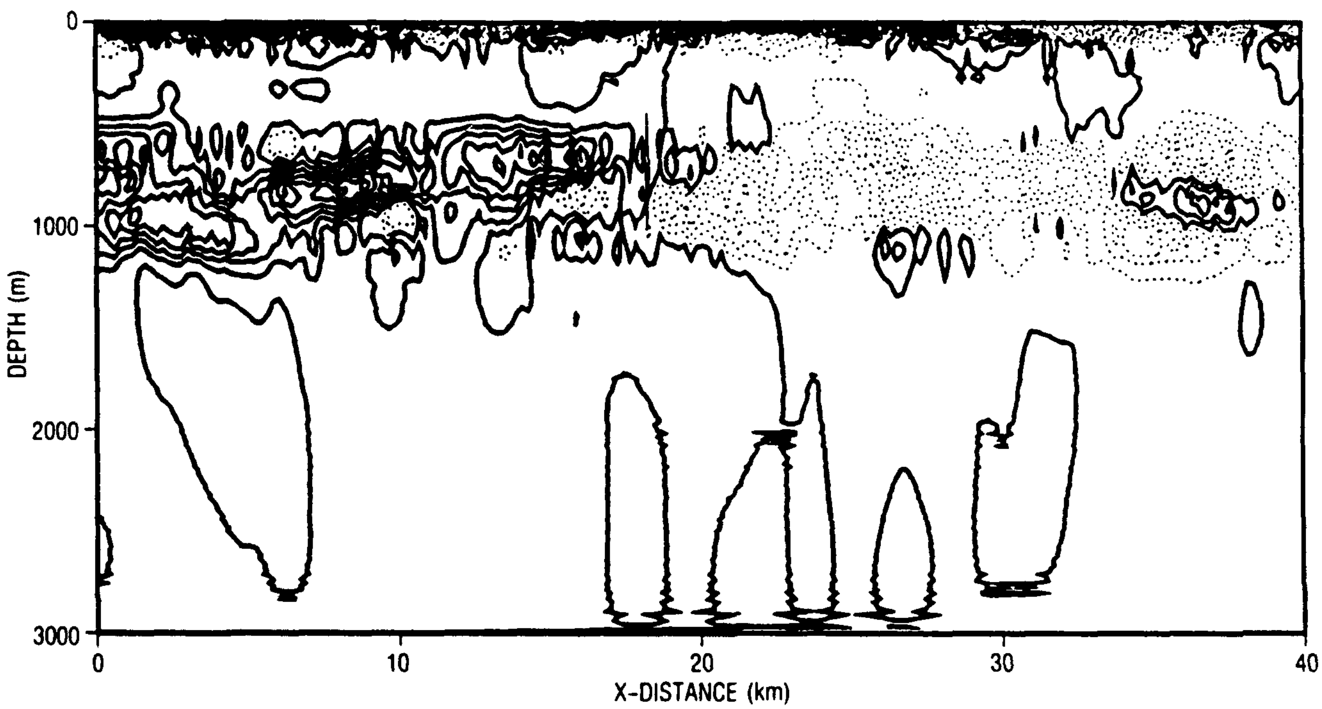

Figure 7. Contour plot of sound velocity anomaly, produced by MODEL1_CONTOUR. A slowly varying field near zero causes the ragged contours in the lower part of the diagram. Contour interval = 0.200.

DISSPLA metafiles that contain internal wave distribution plots are generated. Figure 8 shows a sample VAX/VMS command file for program execution. Figure 9 shows a sample plot of horizontal distribution. Figure 10 shows a sample plot of vertical distribution.

MODEL1_UVW_READ. Time (NT), horizontal region (NX), depth (NZ), and delta values (DT, DX, DZ), are displayed first. Prompts are used to acquire information about decimation rates for the horizontal and vertical direction. These inputs are used as indices for reading U,V, and W fields in MODEL1.DAT. Output is written to the user's terminal.

MODEL1_CTL_LIST. There are no input prompts for MODEL1_CTL_LIST. The contents of the control data file, MODEL1.CTL, are displayed on the user's terminal.

MODEL1_LOOK. Input prompts are used to acquire information about field minimum, maximum, and delta values. These values are used as indices for depth and for the horizontal region. Model displacement fields that contain the file MODEL1.DAT are displayed on the user's terminal.

MODEL1_EIG_LOOK. Input prompts acquire information about desired iteration number, horizontal field, number of frequencies, and number of modes. Plots of the horizontal field are generated using the desired iteration number and designated frequencies and modes. Values for horizontal fields and associated frequency, mode, and wave number are listed.

MODESUB_TEST. Input prompts are used to acquire information about position, season, depth, and frequency. Internal wave modes for Brunt-Väisälä frequency profiles are computed and written as a DISSPLA metafile. Figure 11 contains a sample VAX/VMS command file for program execution. Figure 12 contains a sample output plot.

DISPERSION. Prompts are used to acquire information on position, season, depth, number of frequencies, and number of modes. Modal dispersion diagrams for a Brunt-Väisälä frequency profile at a given location and season are written as a DISSPLA metafile. Figure 13 contains a sample VAX/VMS command file for program execution. Figure 14 contains a sample output plot.

```
$! COMMAND FILE FOR USING MODEL1__ENERGY TO
$! CREATE PLOT FILES OF OCEAN SIMULATION MODEL1
$! INTERNAL WAVE ENERGIES
$!
$! NOTES.
$! "STD00001.DAT" IS THE DISSPLA DEVICE SPECIFIC FILE
$! NAME FOR THE DEC LN03 LASER PRINTER.
$!
$! DISSPLA APPENDS PLOTS TO EXISTING DEVICE SPECIFIC FILES.
$! DELETE OR RENAME EXISTING VERSIONS TO AVOID UNINTENTIONAL
$! PLOT APPENDING.
$!
$! "DISS105" IS A COMMAND WHICH INVOKES THE DISSPLA
$! POST-PROCESSOR. THE POST PROCESSOR GENERATES
$! DEVICE SPECIFIC PLOT FILES. HERE, THE LN03 SPECIFIC
$! PLOT FILE IS NAMED STD00001.DAT
$!
$! "LN03" IS A COMMAND THE SENDS A FILE TO THE LN03
$! PRINT QUEUE
$!
$!
$!
$DELETE STD00001.DAT;*              ! AVOID PLOT APPENDING
$!
$RUN MODEL1__ENERGY
YES                                 ! PROGRAM INPUT - A GENERIC BRUNT-
$!                                                    VAISALA PROFILE
$!
$DISS105                            ! CREATE DEVICE SPECIFIC FILE
12                                  ! POST-PROCESSOR DIRECTIVE
MODI=1-END(HWROT=MOVIE)$            ! POST-PROCESSOR DIRECTIVE
LN03 STD00001.DAT                   ! PRINT THE PLOT FILES
```

Figure 8. VAX/VMS Command file listing for running MODEL1_ENERGY and plotting the results.

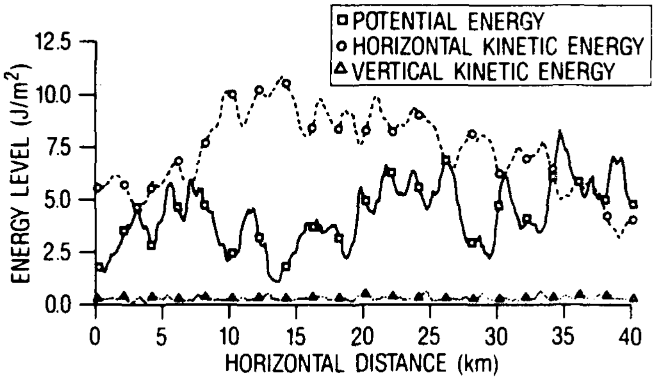

Figure 9. Horizontal energy distribution produced using the command file in Figure 8.

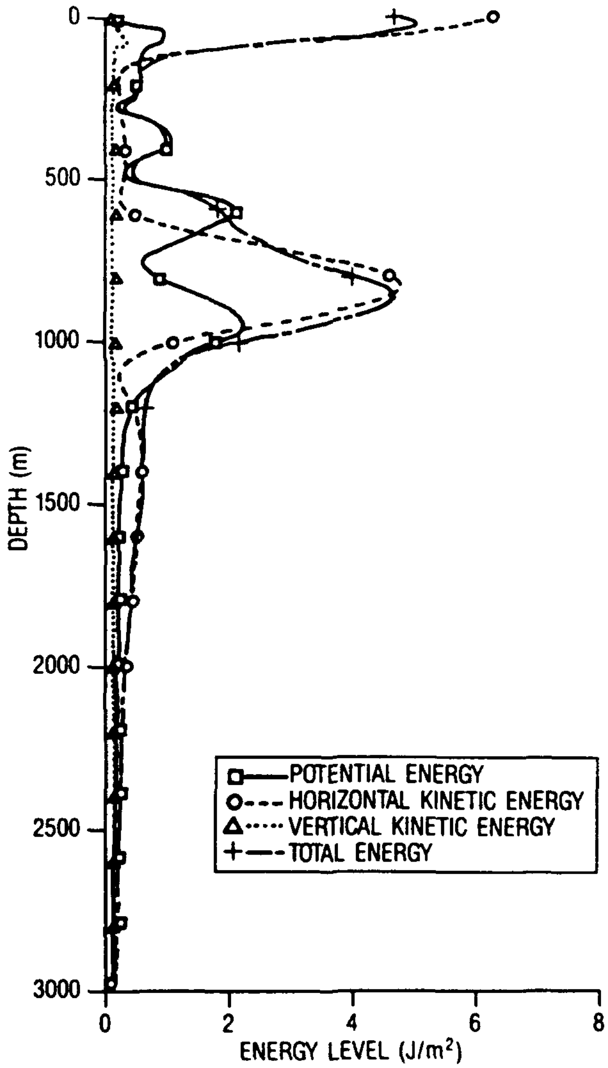

Figure 10. Vertical energy distribution produced using the command file in Figure 8.

```
$! COMMAND FILE FOR USING MODESUB_TEST TO
$! CREATE A PLOT FILE OF OCEAN SIMULATION MODEL1
$! INTERNAL WAVE MODES FOR BRUNT-VAISALA FREQUENCY
$! PROFILES
$!
$! NOTES:
$! "STD00001.DAT" IS THE DISSPLA DEVICE SPECIFIC FILE
$! NAME FOR THE DEC LN03 LASER PRINTER.
$!
$! DISSPLA APPENDS PLOTS TO EXISTING DEVICE SPECIFIC FILES.
$! DELETE OR RENAME EXISTING VERSIONS TO AVOID UNINTENTIONAL
$! PLOT APPENDING.
$!
$! "DISS105" IS A COMMAND WHICH INVOKES THE DISSPLA
$! POST-PROCESSOR. THE POST PROCESSOR GENERATES
$! DEVICE SPECIFIC PLOT FILES. HERE, THE LN03 SPECIFIC
$! PLOT FILE IS NAMED STD00001.DAT
$!
$! "LN03" IS A COMMAND THE SENDS A FILE TO THE LN03
$! PRINT QUEUE
$!
$!
$!
$DELETE STD00001.DAT;*              ! AVOID PLOT APPENDING
$!
$R MODESUB_TEST
30,-70                             ! PROGRAM INPUT - LOCATION
SUMMER                             ! PROGRAM INPUT - SEASON
3000,10                            ! PROGRAM INPUT - DEPTH MAX & MIN
2.0                                ! PROGRAM INPUT - FREQUENCY
$!
$DISS105                           ! CREATE DEVICE SPECIFIC FILE
12                                 ! POST-PROCESSOR DIRECTIVE
MODI=1-END(HWROT=MOVIE)$           ! POST-PROCESSOR DIRECTIVE
LN03 STD00001.DAT                  ! PRINT THE PLOT FILE
```

Figure 11. VAX/VMS Command file for running MODESUB_TEST.

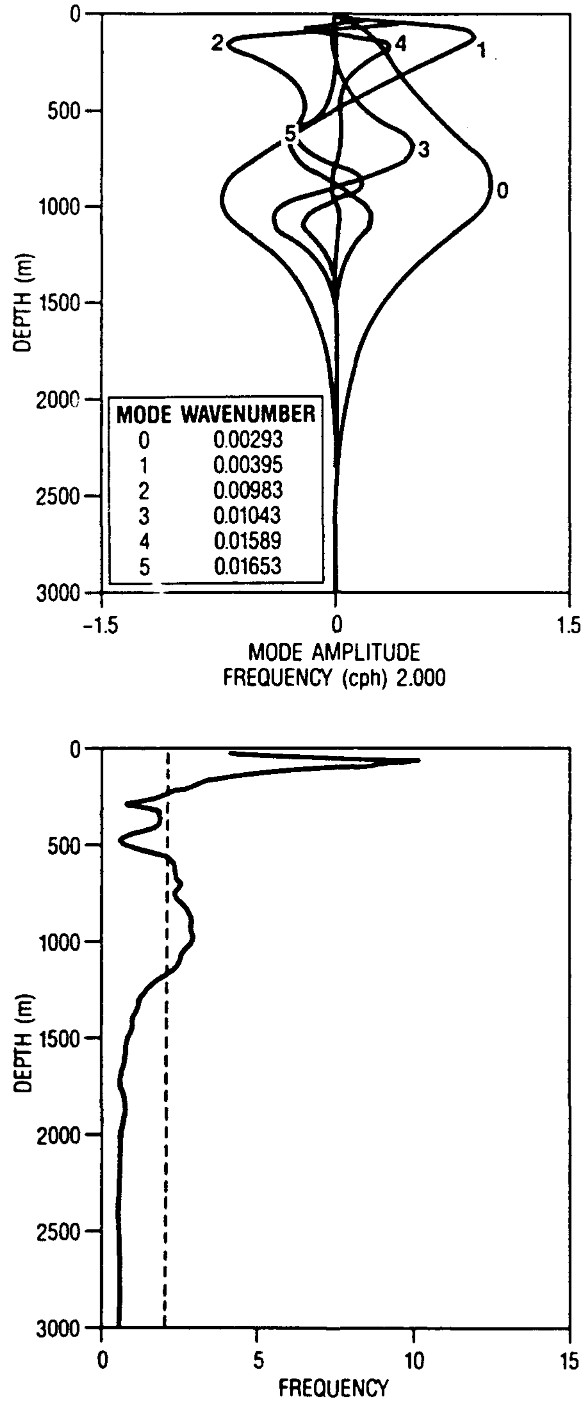

Figure 12. Plot output from the command file in Figure 11, showing the modes for the Brunt-Väisälä frequency profile at 30°N, 70°W at 2 cph, which is plotted on the right.

```
$! COMMAND FILE FOR USING DISPERSION TO
$! CREATE A PLOT FILE OF OCEAN SIMULATION MODEL1
$! MODAL DISPERSION DIAGRAMS
$!
$! NOTES:
$! "STD00001.DAT" IS THE DISSPLA DEVICE SPECIFIC FILE
$! NAME FOR THE DEC LN03 LASER PRINTER.
$!
$! DISSPLA APPENDS PLOTS TO EXISTING DEVICE SPECIFIC FILES.
$! DELETE OR RENAME EXISTING VERSIONS TO AVOID UNINTENTIONAL
$! PLOT APPENDING.
$!
$! "DISS105" IS A COMMAND WHICH INVOKES THE DISSPLA
$! POST-PROCESSOR. THE POST PROCESSOR GENERATES
$! DEVICE SPECIFIC PLOT FILES. HERE, THE LN03 SPECIFIC
$! PLOT FILE IS NAMED STD00001.DAT
$!
$! "LN03" IS A COMMAND THE SENDS A FILE TO THE LN03
$! PRINT QUEUE
$!
$!
$!
$DELETE STD00001.DAT;*          ! AVOID PLOT APPENDING
$!
$RUN DISPERSION
30,-70                          ! PROGRAM INPUT - LOCATION
SUMMER                          ! PROGRAM INPUT - SEASON
3000,10                         ! PROGRAM INPUT - DEPTH MAX & MIN
100                             ! PROGRAM INPUT - # OF FREQUENCIES
5                               ! PROGRAM INPUT - # OF MODES
$!
$DISS105                        ! CREATE DEVICE SPECIFIC FILE
12                              ! POST-PROCESSOR DIRECTIVE
MODI=1-END(HWROT=MOVIE)$        ! POST-PROCESSOR DIRECTIVE
LN03 STD00001.DAT               ! PRINT THE PLOT FILE
```

Figure 13. VAX/VMS Command file listing for running DISPERSION.

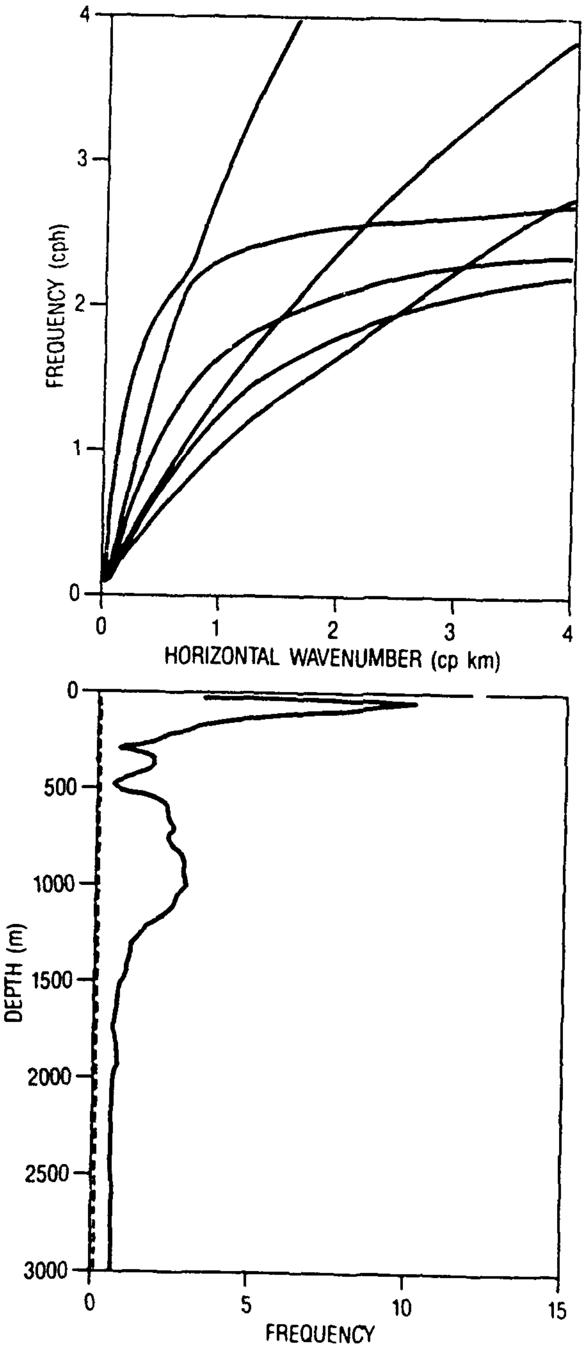

Figure 14. Plot of the output from DISPERSION, showing the linear internal wave dispersion diagram for the Brunt-Väisälä frequency profile plotted on the right.

VI. Conclusions

The first-level ocean simulation was designed to provide a capability for simulating the perturbations to the temperature, salinity, and velocity fields due to internal wave and tidal activity in midocean conditions. It was designed to be portable and easy to use and maintain. The simulation was therefore written in standard FORTRAN77 and has been tested on Digital Equipment Corporation's VAX computers, using the VMS operating system, and on a CONVEX computer, using the UNIX operating system. The program should operate properly on any other system, provided the record lengths of the direct access files are suitable.

VII. Recommendations

This program should be used for acoustic field simulation, cruise planning, mooring motion simulation, and general ocean system modeling. Further development of the internal tidal structure, particularly the propagation of the internal tide in shallow coastal regions, is needed to make the simulation more realistic and useful on continental shelf regions. The inclusion of varying bottom depths and variable output data structures would make the program more useful to the acoustic modeling community.

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Appendix

Structure and Layer Diagrams

MODEL1 Program Structure

```
MAIN PROGRAM
  |
  CONTROL_INPUT
    OPEN OUTPUT FILES
    EIG_CONTROL
  |
  PROFILE_INPUT
  |
  INT_WAVE_SIMULATION
     (TIME LOOP)
          (X - LOOP)
             DISPLACE
             PROFILE_CALC
             (Z - LOOP)
               (OUTPUT --> MODEL1.DAT)
             (END ZLOOP)
          (END X - LOOP)
     (END TIME - LOOP)
```

MODEL1 Program Layering

```
  MAIN
  |
--------------------------------------
  |                |                 |
  CONTROL_INPUT    PROFILE_INPUT     INT_WAVE_SIMULATION
  |                   |                   |
--------------        |                   |
|            |        |                   |
OPEN OUTPUT  |        |                   |
FILES        |        |                   |
        EIG_CONTROL   |                   |
                      |                   |
                      |                   |
              -------------------------   |
              |      |       |       |    |
              LINT   INTRPL  BVFREQ  DIST |
                                          |
                                      ----------------
                                      |             |
                                      DISPLACE     PROFILE_CALC
                                      |
                               ----------------------
                              |            |        |
                              MODESUB      SZ       INTERP
                                 |
                    ---------------------------
                    |      |         |        |
                    TURN   NUMEROV   INTERP   AVGINT
```

MODEL1_EXPORT Program Structure

```
MAIN
  |
  PARSE (MODEL1.AUX)
  |
  INTERACTIVE TERMINAL INPUT
  |
  OPEN MODEL1.DAT & MODEL1.UV
  |
  COMPUTE PLOT FIELDS
  |
  WRITE FIELDS => MODEL1.PC
```

MODEL1_EXPORT Program Layering

```
Main
|
----------------------------------------------------------
|          |            |                   |            |
PARSE      |            |                   |            |
MODEL1.AUX |            |                   |            |
           INTERACTIVE  |                   |            |
           INPUT        |                   |            |
                        OPEN MODEL1.DAT     |            |
                        & MODEL1.UV         |            |
                                        COMPUTE PLOT     |
                                         FIELDS          |
                                                         WRITE FIELDS
```

MODEL1_SV_EXPORT Program Structure

```
MAIN
|
PARSE (MODEL1.AUX)
|
OPEN MODEL1.DAT
|
COMPUTE SVEL (SOUND VELOCITY)
|
OUTPUT => ASCII FILE CONTAINING
          SOUND VELOCITY FIELD
```

MODEL1_SV_EXPORT Program Layering

```
MAIN
|
-----------------------------------------------
|              |             |                  |
PARSE          |             |                  |
MODEL1.AUX     |             |                  |
               OPEN          COMPUTE            |
               MODEL1.DAT    SOUND VELOCITY     |
                                              OUTPUT => ASCII FILE
```

LEVASC Program Structure

```
MAIN
|
OPEN LEVITUS.DAT (BINARY FORMAT)
|
LOOP
   READ LEVITUS.DAT
   |
   WRITE LEVITUS.ASC (ASCII FORMAT)
END LOOP
```

LEVASC Program Layering

```
MAIN
|
---------------------------
|                          |
OPEN LEVITUS.DAT           LOOP
                             READ  LEVITUS.DAT
                             |
                             WRITE LEVITUS.ASC
```

ASCLEV Program Structure

```
MAIN
|
OPEN LEVITUS.ASC (ASCII FORMAT)
|
LOOP
   READ LEVITUS.ASC
   |
   WRITE LEVITUS.DAT (BINARY FORMAT)
END LOOP
```

ASCLEV Program Layering

```
MAIN
|
----------------------------
|                          |
OPEN LEVITUS.ASC           LOOP
                             READ  LEVITUS.ASC
                             |
                             WRITE LEVITUS.DAT
```

MODEL1_PLOT Program Structure

```
MAIN PROGRAM
  PARSE (MODEL1.AUX)
   |
  INTERACTIVE INPUT
   |
  OPEN MODEL.DAT & MODEL1.UV
   |
  ESTABLISH PLOTTING FEATURES
      UIS$CREATE_COLOR_MAP
      UIS$CREATE_DISPLAY
      UIS$CREATE_WINDOW
      UIS$HSV_TO_RGB
      UIS$SET_COLOR
      UIS$SET_WRITING_INDEX
      UIS$SET_LINE_WIDTH
      UIS$PLOT
   |
  PERFORM PLOT
   |
  ESTABLISH COLOR SCALE
      UIS$PLOT
      UIS$SET_FONT
      UIS$NEW_TEXT_LINE
      UIS$TEXT
   |
  CREATE COLOR SCALE
```

MODEL1_PLOT Program Layering

```
MAIN
|
------------------------------------------------------------------
|           |         |      |                  |      |        |
PARSE       |         |      |                  |      |        |
MODEL1.AUX  |         |      |                  |      |        |
        INTERACTIVE   |      |                  |      |        |
        INPUT         |      |                  |      |        |
                    OPEN     |                  |      |        |
               MODEL1.DAT    |                  |      |        |
               & MODEL1.UV   |                  |      |        |
                             |                  |      |        |
                    PLOT FEATURES               |      |        |
                        UIS$CREATE_COLOR_MAP    |      |        |
                        UIS$CREATE_DISPLAY      |      |        |
                        UIS$CREATE_WINDO        |      |        |
                        UIS$HSV_TO_RGB          |      |        |
                        UIS$SET_COLOR           |      |        |
                        UIS$SET_WRITING_INDEX   |      |        |
                        UIS$SET_LINE_WIDTH      |      |        |
                        UIS$PLOT                |      |        |
                                                |      |        |
                                        PERFORM PLOT   |        |
                                                       |        |
                                             EST. COLOR SCALE   |
                                             UIS$PLOT           |
                                             UIS$SET_FONT       |
                                             UIS$NEW_TEXT_LINE  |
                                             UIS$TEXT           |
                                                                |
                                                           CREATE
                                                      COLOR SCALE
```

MODEL1_CONTOUR Program Structure

```
MAIN
|
INTERACTIVE TERMINAL INPUT
|
PARSE (MODEL1.AUX)
|
OPEN MODEL1.DAT & MODEL1.UV
|
ESTABLISH PLOT PARAMETERS
|
COMPUTE PLOT FIELDS
   SVEL
|
GRAPHICS SUBROUTINES
   COMPRS
   BCOMMON
   PAGE
   SCMPLX
   AREA2D
   HEADIN
   YNAME
   XNAME
   GRAF
   FRAME
   CONMAK
   CONLIN
   CONTUR
   ENDPL
   DONEPL
|
OUTPUT => DISSPLA PLOT METAFILE
```

MODEL1_CONTOUR Program Layering

```
MAIN
|
------------------------------------------------------------
|           |       |         |              |             |
INTERACTIVE |       |         |              |             |
INPUT       |       |         |              |             |
            PARSE   |         |              |             |
         MODEL1.AUX |         |              |             |
                    OPEN      |              |             |
                   MODEL1.DAT |              |             |
                   MODEL1.UV  |              |             |
                              ESTABLISH PLOT |             |
                              PARAMETERS     |             |
                                             COMPUTE PLOT  |
                                             FIELDS        |
                                               |           |
                                               SVEL   GRAPHICS
                                                      SUBROUTINES
                                                           |
                                                         COMPRS
                                                         BCOMMON
                                                         PAGE
                                                         SCMPLX
                                                         AREA2D
                                                         HEADIN
                                                         YNAME
                                                         XNAME
                                                         GRAF
                                                         FRAME
                                                         CONMAK
                                                         CONLIN
                                                         CONTUR
                                                         ENDPL
                                                         DONEPL
                                                       |
                                                  OUTPUT => DISSPLA
                                                    PLOT METAFILE
```

MODEL1_ENERGY Program Structure

```
MAIN
|
INTERACTIVE TERMINAL INPUT
|
PARSE (MODEL1.AUX)
|
OPEN MODEL1.DAT & MODEL1.UV
|
ESTABLISH PLOT PARAMETERS
|
COMPUTE PLOT FIELDS
|
OUTPUT => ENERGY.LIS
|
GRAPHICS SUBROUTINES
 COMPRS
  |
 REPEAT FOR EACH PLOT
   SETCLR
   PAGE
   AREA2D
   TRIPLX
   HEIGHT
   HEADIN
   YNAME
   XNAME
   GRAF
   LINES
   LEGLIN
   CONLIN
   SCLPIC
   CURVE
   DASH
   DOT
   LEGEND
   |
   OUTPUT => DISSPLA METAFILE
   RESET
```

MODEL1_ENRGY Program Layering

```
MAIN
|
---------------------------------------------------------------
|           |          |         |       |          |         |
INTERACTIVE |          |         |       |          |         |
TERMINAL    |          |         |       |          |         |
INPUT     PARSE        |         |       |          |         |
          MODEL1.AUX   |         |       |          |         |
                    OPEN         |       |          |         |
                    MODEL1.DAT   |       |          |         |
                    MODEL1.UV    |       |          |         |
                              EST. PLOT  |          |         |
                              PARAMETERS |          |         |
                                       COMPUTE      |         |
                                     PLOT FIELDS    |         |
                                                 OUTPUT=>     |
                                                 ENERGY.LIS   |
                                                         GRAPHICS
                                                         COMPRS
                                                          |
                                             REPEAT FOR EACH PLOT
                                                        SETCLR
                                                        PAGE
                                                        AREA2D
                                                        TRIPLX
                                                        HEIGHT
                                                        HEADIN
                                                        YNAME
                                                        XNAME
                                                        GRAF
                                                        LINES
                                                        LEGLIN
                                                        CONLIN
                                                        SCLPIC
                                                        CURVE
                                                        DASH
                                                        DOT
                                                        LEGEND
                                                        ENDPL
                                                         |
                                                OUTPUT=>REGIS FILE
                                                         |
                                                         RESET
                                                         |
                                                         DONEPL
```

MODEL1_UVW_READ Program Structure

```
MAIN
|
PARSE (MODEL1.AUX)
|
INTERACTIVE TERMINAL INPUT
|
OPEN MODEL1.UV
|
READ MODEL1.UV
|
OUTPUT => UV FIELDS
```

MODEL1_UVW_READ Program Layering

```
MAIN
|
-------------------------------------------------
|            |             |           |            |
PARSE        |             |           |            |
MODEL1.AUX   |             |           |            |
             INTERACTIVE   |           |            |
             INPUT         |           |            |
                           OPEN        |            |
                           MODEL1.UV   |            |
                                       READ         |
                                       MODEL1.UV    |
                                                    OUTPUT =>
                                                    UV FIELDS
                                                    TO TERMINAL
```

MODEL1_CTL_LIST Program Structure

```
Main
|
OPEN MODEL1.CTL FILE
|
OUTPUT => CTL INFORMATION
```

MODEL1_CTL_LIST Program Layering

```
MAIN
|
-------------------------------
|             |
|             |
OPEN          |
MODEL1.CTL    |
           OUTPUT => CTL
           INFORMATION TO TERMINAL
```

MODEL1_LOOK Program Structure

```
MAIN
|
PARSE (MODEL1.AUX)
|
OPEN MODEL1.DAT
|
READ (MODEL1.DAT FILE)
|
INTERACTIVE TERMINAL INPUT
|
OUTPUT MODAL DISPLACEMENTS
```

MODEL1_LOOK Program Layering

```
MAIN
|
-----------------------------------------------------
|            |            |            |               |
|            |            |            |               |
PARSE        |            |            |               |
MODEL1.AUX   |            |            |               |
            OPEN          |            |               |
            MODEL1.DAT    |            |               |
                         READ          |               |
                         MODEL1.DAT    |               |
                                      INTERACTIVE      |
                                      TERMINAL INPUT   |
                                                      OUTPUT => MODAL
                                                      DISPLACEMENTS
                                                        TO TERMINAL
```

MODEL1_EIGLOOK Program Structure

```
MAIN
|
PARSE (MODEL1.AUX)
|
OPEN MODEL1.EIG
|
GRAPHICS SUBROUTINES
 COMPRS
 |
 REPEAT FOR EACH PLOT
   SETCLR
   PAGE
   AREA2D
   FASHION
   HEIGHT
   HEADIN
   XNAME
   YNAME
   GRAF
   MESSAG
   INTNO
   CURVE
   ENDPL
 |
 OUTPUT => DISSPLA METAFILE
 |
 DONPL
```

MODEL1_EIGLOOK Program Layering

```
MAIN
|
--------------------------------
|              |               |
PARSE          |               |
MODEL1.AUX     |               |
               OPEN            |
               MODEL1.EIG      |
                               GRAPHICS SUBROUTINES
                               |
                               COMPRS
                               |
                               REPEAT FOR EACH PLOT
                                 |
                                 SETCLR
                                 PAGE
                                 AREA2D
                                 FASHION
                                 HEIGHT
                                 HEADIN
                                 XNAME
                                 YNAME
                                 GRAF
                                 MESSAG
                                 INTNO
                                 CURVE
                                 ENDPL
                                |
                                OUTPUT => DISSPLA METAFILE
                                |
                                DONPL
```

MODESUB_TEST Program Structure

```
MAIN
|
CONTROL_INPUT
  OPEN TEST_DIAGNOSTICS.LIS
|
PROFILE_INPUT
  OPEN LEVITUS.DAT
  LINT
  INTERPL
  BVFREQ
 OUTPUT => TEST_DIAGNOSTICS.LIS
|
INT_WAVE_SIMULATION
  DISPLACE
    MODESUB
    GRAPHICS SUBPROGRAMS
       SET PLOT FEATURES
       (LOOP FOR EACH INTERNAL WAVE MODE)
          OUTPUT => DISSPLA METAFILE
       (END LOOP)
       BRUNT-VAISALA FREQUENCY PROFILE PLOTS
          OUTPUT => DISSPLA METAFILE
```

```
                         MODESUB_TEST Program Layering
MAIN
|
-----------------------------------------------------
|                         |                          |
CONTROL_INPUT             |                          |
|                         |                          |
OPEN TEST_DIAGNOSTICS.LIS |                          |
                     PROFILE_INPUT                   |
                          |                          |
--------------------------------------               |
|           |     |      |      |    |               |
OPEN        LINT  INTRPL BVFREQ DIST OUTPUT =>       |
LEVITUS.DAT                     TEST_DIAGNOSTICS.LIS |
                                                     |
                                        INT_WAVE_SIMULATION
                                                     |
                                                  DISPLACE
                                                     |
          -----------------------------------------------------
          |                                                   |
        MODESUB                                           GRAPHICS
          |                                            SUBPROGRAMS
 ---------------------------                                  |
|        |        |        |       --------------------------------
 TURN  NUMEROV  INTERP  AVGINT     |               |              |
                        SET PLOT FEATURES  REPEAT FOR EACH      FREQ
                                   |   INTERNAL WAVE MODE     PROFILE
                                 COMPRS            |              |
                                 SETDEV          CURVE          PHYSOR
                                 PAGE              |            AREA2D
                                 PHYSOR         OUTPUT =>       SERIF
                                 AREA2D         POPFIL.DAT      SHDCHR
                                 SERIF                          HEIGHT
                                 SHDCHR                         HEADIN
                                 HEIGHT                         XNAME
                                 HEADIN                         YNAME
                                 XNAME                          GRAF
                                 YNAME                          FRAME
                                 GRAF                           CURVE
                                 FRAME                          DASH
                                 GRACE                          CURVE
                                                                ENDGR
                                                                ENDPL
                                                 OUTPUT => POPFIL.DAT
                                                                DONEPL
```

DISPERSION Program Structure

```
MAIN
|
CONTROL_INPUT
  OPEN TEST_DIAGNOSTICS.LIS
|
PROFILE_INPUT
  OPEN LEVITUS.DAT
  INTERPL
  BVFREQ
  OUTPUT => TEST_DIAGNOSTICS.LIS
|
INT_WAVE_SIMULATION
  DISPLACE
    MODESUB
    GRAPHICS SUBPROGRAMS
       SET PLOT FEATURES
       (LOOP FOR EACH INTERNAL WAVE MODE)
          OUTPUT => DISSPLA METAFILE
                    POPFIL.DAT
       (END LOOP)
       BRUNT-VAISALA FREQUENCY PROFILE PLOTS
          OUTPUT => DISSPLA METAFILE
```

```
                         DISPERSION Program Layering

MAIN
|
-----------------------------------------------------
|                            |                        |
CONTROL_INPUT                |                        |
|                            |                        |
OPEN TEST_DIAGNOSTICS.LIS    |                        |
                      PROFILE_INPUT                   |
                             |                        |
--------------------------------------                |
|           |     |      |      |    |                |
INPUT       LINT  INTRPL BVFREQ DIST OUTPUT =>        |
LEVITUS.DAT                           TEST_DIAGNOSTICS.LIS |
                                                      |
                                            INT_WAVE_SIMULATION
                                                      |
                                                  DISPLACE
                                                      |
         -----------------------------------------------------
         |                                                    |
       MODESUB                                              GRAPHICS
         |                                               SUBPROGRAMS
 ---------------------------                                  |
|        |         |       |     -------------------------------
 TURN  NUMEROV  INTERP  AVGINT    |              |            |
                        SET PLOT FEATURES  REPEAT FOR EACH  FREQ
                                  |    INTERNAL WAVE MODE  PROFILE
                               COMPRS            |            |
                               SETDEV         CURVE        PHYSOR
                               PAGE              |         AREA2D
                               PHYSOR       OUTPUT =>      SERIF
                               AREA2D       POPFIL.DAT     SHDCHR
                               SERIF                       HEIGHT
                               SHDCHR                      HEADIN
                               HEIGHT                      XNAME
                               HEADIN                      YNAME
                               XNAME                       GRAF
                               YNAME                       FRAME
                               GRAF                        CURVE
                               FRAME                       DASH
                               GRACE                       CURVE
                                                           ENDGR
                                                           ENDPL
                                            OUTPUT => POPFIL.DAT
                                                           DONEPL
```

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13. Abstract *(Maximum 200 words).*

Oceanographic simulation models are valuable tools for imitating temperature, salinity, density, sound velocity, and other environmental areas of naval interest. The Naval Oceanographic and Atmospheric Research Laboratory was tasked to implement and operate ocean simulation models. This manual presents the theoretical foundations for the first version of the model, the details of the primary model's structure, and the computer programs and instructions for implementing and using the model.

The first version of the model was based on the premise that the most important features of interest to the Navy are produced by internal waves. Subsequent versions of the model will incorporate variability produced by shear, fronts, mixed-layer processes and turbulent mixing. A full three-dimensional, time-varying model is expected in about three years.

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